Force and Correlation Length in Cables in Steady Flow

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Grant #: N00014-95-1-1106
http://web.mit.edu/towtank/www/

LONG-TERM GOAL

To map experimentally basic flow-structure interaction mechanisms relevant to the vortex-induced vibrations of marine cables subject to shear currents, so as to develop better predictive tools.

OBJECTIVES

To map the parametric dependence of the forces and motions of long flexible bluff cylinders in cross flow, and describe basic mechanisms of their wake, using simultaneously whole-field visualization and a closed-loop force feedback apparatus. To use the experimental apparatus to simulate systems with complex structural impedance, such as marine cables and risers. To derive predictive models based on sectional force and flow measurements and correlation length studies. To corroborate the predictive models against experimental measurements on flexible tethers.

APPROACH

We employ a combined experimental, computational and theoretical approach, using extensively a hybrid experimental apparatus allowing simulation and experiment linked in real-time through force feedback. Experiments are conducted in the Testing Tank Facility, which contains a large water tank (100 ft by 8 ft by 4 ft), and a smaller tank (8 ft by 2 ft by 1 ft). It is equipped with Digital Particle Image Velocimetry (DPIV) and Particle Tracking Velocimetry (PTV) apparatus, allowing quantitative wake mapping; as well as extensive apparatus for measuring forces on cylinders.

We employ extensively the Virtual Cable Testing Apparatus (VCTA), which allows testing of cylinders in virtual free-vibration conditions (Hover et al. 1997, 1999). The apparatus has been designed and developed to simultaneously simulate the motions of a structure with complex dynamics, while coupled with real-time, experimentally measured wake dynamics.

A hybrid virtual system can be simulated, employing a closed-loop control system which consists of a pair of force transducers measuring the transverse forces at both ends of a cylindrical test section moving forward at constant speed; a dedicated computer which uses in real-time the measured force to drive a numerical simulation of an equivalent system of desired structure; and two servomotors and linear tables which impose, also in real-time, the numerically calculated motion to the cylinder section. The apparatus results in an effective system with arbitrary internal structure.

VCTA has been used to simulate a mass-dashpot-spring system vibrating freely with very low effective damping, as well as complex systems with several natural frequencies, including mode-coalescence conditions, and systems with nonlinear stiffness characteristics (Hover et al. 1998ab). Work is conducted by M. Triantafyllou and F. Hover.

WORK COMPLETED

We have mapped experimentally the response of a flexibly mounted cylinder in cross flow when subjected to an additional, external harmonic forcing. This is a generic problem modeling the essence of cable response in a shear current, when different parts of the cable provide excitation at different frequencies; then each segment of the cable participates in locally excited vibration, as well as vibrations which have been transmitted from other sections of the cable.

We have developed dual VCTA apparatus to model the vibrations of bluff cylinders when in the wake of another body. The new apparatus is designed to reach Reynolds numbers up to 100,000 and can simulate free vibration as well as forced vibration conditions.

We have modeled the impact of non-circular section in marine cables, by attaching small wires along the axis of rigid circular sections at various locations and have conducted experiments to map the parametric dependence of the response.

We have compared the response of a flexibly mounted rigid cylinder, allowed to oscillate transversely to the flow, with the response of a flexible cylinder. The results provide much needed information on the validity of using rigid cylinder data to model the vibration of flexible extended systems.

We have continued developing a predictive computer model, based on experimental results, and we can compare side by side predictions based on sectional data with real-time experiments.

RESULTS

We have obtained detailed information on the forces and responses of a flexibly mounted cylinder when an additional harmonic force is superposed. This models the situation of bluff bodies in shear flow, when two or more frequencies of response co-exist, as vortex shedding occurs at different frequencies along the length. We have conducted experiments at several ratios of forcing frequency to Strouhal frequency, establishing the parametric dependence of the amplitude and frequency of response, the drag coefficient, and the added mass and lift coefficient in phase with velocity. These are essential data for developing predictive tools, and exhibit basic changes introduced by the additional forcing in both the onset and range of lock-in and the magnitude of the forces.

We have compared in detail the response of flexibly mounted rigid cylinders, allowed to vibrate only transversely, with the response of flexible cylinders, under nearly identical mass ratios and damping parameters and with similar natural frequencies. We have shown that although the responses are qualitatively similar, there exist quantitative as well as certain qualitative differences, which we are currently exploring further. In the attached figures we show the comparison between the two configurations; the flexible cylinder response is characterized by a larger peak transverse amplitude, occurring at a slightly higher reduced velocity, large in-line oscillations, and an absence of sustained frequency lock-in.

Figures 1 and 2 show the measured responses of a rigid cylinder flexibly mounted and the responses of a flexible cylinder as functions of the reduced velocity *Vrn=U/(f_n d),* where *U* is the speed of tow, f_n the natural frequency of the cylinder and d the diameter. The following quantities are shown: a) one-tenth highest oscillation amplitude ratio (●-transverse, ○-in-line), b) mean drag coefficient, c) fluctuating drag coefficient, d) ratio of transverse oscillation frequency to natural frequency of cylinder. As shown the curves are overall similar but there are areas with differences reflecting corresponding differences in the governing physical mechanisms.

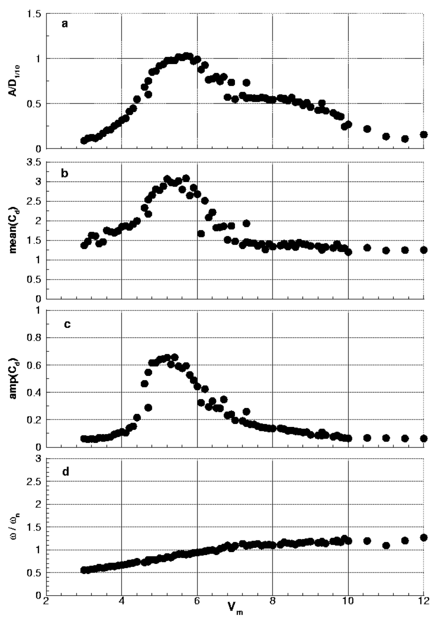

Figure 1. Rigid cylinder results as a function of Vrn.

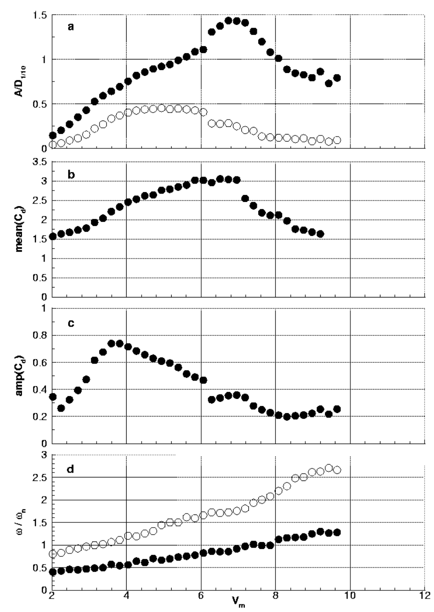

Figure 2. Flexible cylinder results as a function of Vrn.

We have continued our investigation of the formation of hybrid modes (Techet et al. 1998, Hover et al. 1998a), which is confirmed to occur at higher Reynolds numbers. We are using a new apparatus with 2-meter span, which allows better studies of correlation length using flow visualization to detect pattern variations along the span.

In two analytical/numerical studies we have derived the properties of the natural frequencies and modes of beams under tension; and we have also described the properties of vibrating beams with slowly varying inhomogeneities, which can drastically affect the vibratory response.

We have continued our study of the impact of having a cylinder with inhomogeneities, such as caused by the helical construction of marine cables, or by attachments to the cylinder. Our generic model is to attach on the section of a circular cylinder two or several small wires, and at various angles with respect to the front stagnation point. We have mapped the parametric dependence of the forces and wake features, showing similarity to the transitions found in the critical regime for smooth cylinders, once a threshold Reynolds number is achieved.

IMPACT/APPLICATION

The results showing the impact of external forcing on the free vibration of beams will impact the modeling efforts to predict vibrations of cylinders in shear flows.

Comparison of the free vibration of flexibly mounted rigid cylinders versus flexible cylinders provides further needed information to assess the validity of using rigid cylinder data to model the vibrations of cables and beams.

Continuing work on the hybrid mode formation, which is shown to persist at high Reynolds numbers, impacts our understanding of correlation length modeling.

TRANSITIONS

The results from this study have been applied in the development of predictive codes for vibrating cables, beams and risers in water, which are now being used by the offshore and marine industry (Triantafyllou et al. 1999).

RELATED PROJECTS

We have a working relation with Prof. Karniadakis of Brown University, and Dr. Mark Grosenbaugh of Woods Hole Oceanographic Institution.

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